MATHEMATICAL MODELLING OF BOREHOLE GROUTING IN PERMAFROST

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Abstract: The process of borehole grouting in the regions of permafrost is more complicated than in normal climatic conditions due to the possible thawing of the frozen rock, which can be induced by the heat produced during cement hydration. In order to prevent thawing of the surrounding formation, the main conditions that should be imposed on the grouting off technology and properties of the cementing slurries are rapid cement hydration and low heat generation during chemical reaction. Mathematical model of the grouting off process in permafrost, presented in this study, accounts for heat transferred from the borehole circulating mud and heat generated due to cement hydration. The problem is solved analytically by the approximate integral-heat-balance method. As a result, the close-form solutions for the temperature field in the cemented region and surrounding formation are obtained. On the basis of these analytical solutions, analytical criteria for the borehole grouting off regimes that take place without thawing of the frozen rock are proposed. These criteria can be readily used for assessing physical and chemical properties of the cement slurries and their suitability for grouting off the borehole in permafrost.

1. INTRODUCTION

The heat transfer process plays an important role in a number of industrial applications related to drilling technologies and borehole exploitation. For instance, the process of borehole grouting by the cement slurries is accompanied by generation of significant amount of heat as a result to an exothermic reaction of cement hydration. Assessment of this heat and of the heat transmitted from the circulating mud to the rock formation is of crucial importance, especially for the borehole completion in the region of permafrost where excessive heating is undesirable and may lead to different engineering complications. It is well known that the mud temperature and chemical composition of the cement compounds are the main factors that influence the down-hole performance of cement slurries (Kutasov, 1999). The down-hole temperature controls the pace of chemical reactions during cement hydration resulting in cement setting and strength development. As a mud temperature increases, the cement slurry hydrates and sets faster and develops strength more rapidly. In Arctic wells the cement is set under unfavourable conditions since, on the one hand, external heating of the cement slurry is required for hydration enhancement and, on the other hand, heating of the slurry supplemented by heat produced due to chemical reaction may cause thawing of the frozen rock formation. The latter in turn may lead to deformation and failure of the cemented column behind the casing pipe and further leakage of the cement slurry in thawed area. To this end, sustaining the optimal temperature regime is of primarily importance for the borehole grouting-off in the regions of permafrost. In the present study, interaction of the main parameters that control the grouting process, namely temperature field and thermo-physical and chemical properties of the cement, are modelled by the conjugate heat conduction problem in the cemented column and formation with exponential heat source term due to chemical reaction of cement hydration.

2. SYSTEM MODEL AND ANALYSIS

The axial symmetry of the process is assumed and, therefore, the cylindrical coordinates (r^*, z^*) are employed. In the borehole grouting technology the casing pipe of external radius r_0^* is placed in the borehole of the radius r_w and the gap between the casing tube and the wall of the well is filled by the cement slurry. Fluid in the borehole intensively circulates along the drilling tube (inflow) and annulus between the drilling and casing tubes (outflow). This intensive circulation of the fluid of the appropriate temperature t_L is undertaken in order to provide the proper conditions for cement hardening in the gap behind the casing. Since the radial temperature gradients are much greater than temperature gradients in the vertical direction, the temperature distribution in the cement slurry and surrounding rock can be described by the following non-dimensional mathematical model: